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TECHNICAL MEMORANDUM

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ATMOSPHERIC IR TRANSMISSION MEASUREMENTS IN A TROPICAL MARITIME ENVIRONMENT: COMPARISON WITH THE LOWTRAN 6 MODEL

D.R. Cutten

S U M M A R Y

Broadband IR transmission data measured at a coastal, tropical maritime site have been compared with LOWTRAN 6 model predictions.

Transmittance data for a 7 km path plotted as a function of absolute humidity have been examined in six spectral regions from 1.5 to 12 μm. A significant discrepancy, which increases with water vapour content, has been found between the measured and predicted data for the 8 to 12 μm region. This discrepancy is believed to be due to errors in the laboratory-determined self-broadening coefficients of water continuum absorption.

Reasonable agreement has been obtained in the 4.4 to 5.4 μm and the 3.5 to 4.0 μm regions, particularly for the former region when water continuum absorption is included in the LOWTRAN model.

POSTAL ADDRESS: Director, Electronics Research Laboratory,
Box 2151, GPO, Adelaide, South Australia, 5001.

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1. INTRODUCTION

The current generation of broad-band opto-electronic(OE) surveillance systems in use or proposed for the Australian Defence Force will operate in a wide range of environments in Australia. Performance assessments of such equipments require a knowledge of the intervening atmospheric effects which are assessed initially using computer models such as the AFGL code LOWTRAN(ref.1,2). This model has been developed primarily for the Northern Hemisphere and hence its use in predicting transmission in various Australian environments should be examined.

Transmission in the 8 to 12 μm spectral region is affected predominantly by the water vapour continuum component of the molecular absorption, and the estimated transmission over long paths with high water vapour pressure is very sensitive to changes in the water vapour continuum absorption coefficients. Any errors in the continuum absorption coefficients will dominate the effects of other errors on the transmission. The absorption coefficients are not known with great precision and are generally derived empirically by fitting curves to data obtained from multi-pass absorption cell measurements(ref.3). The mechanism behind the large absorption in the 8 to 12 μm region is still subject to conjecture and hence there is no established theory with which to calculate the coefficients.

The purpose of this paper is to report on IR transmission measurements made over a 7 km pathlength at a tropical maritime coastal site. The tropical site was chosen because it is able to represent closely an "open ocean" tropical maritime atmosphere with high water vapour pressures. Measurements were made in the 1.5 to 2.5, 3.5 to 5.5 μm and 8 to 12 μm spectral regions over the period March 1982 to October 1983. These data are compared with LOWTRAN 6 predictions for similar meteorological conditions and discrepancies observed are discussed.

2. SITE DESCRIPTION

The site selected for the transmission measurements was at the coastal establishment of the Joint Tropical Trials Research Establishment (JTTRE), Cowley Beach, Queensland. Figures 1 and 2 give the location of the site and path used while figure 3 shows a photograph of the path line which was about 3 m above the sea surface. Tide variation at this site generally varied between 0.5 and 2 m. This area was the subject of an earlier 12 month characterisation study in which the site was examined for its suitability as representing the open-ocean maritime tropical environment. The standard meteorological parameters, total particle density, visibility, radon and atomic composition of the aerosol were measured. It was generally observed that with SE to NE winds greater than a few knots, the total particle density and radon count were low, implying the presence of an air mass with a low continental aerosol component. A low particle density for the tropical open-ocean air mass is of the order 400 to 500 /cm^3. Although cane burning occurred nearby in the period July to November, the smoke had dispersed inland from the beach area by midday following the SE trade winds which by that time had developed to 5 to 12 kn. Some surf spray was evident at the beachline when the wind exceeded about 12 kn. However, size distribution data collected with the Particle Measuring Systems (PMS) optical array probe indicated that the number of large particles generated in such a small portion of the path would not have any noticeable affect on the IR transmission. With the reef about 30 km offshore there was the advantage that no large swell was present at the site which would have increased the surf spray. However, the waters inside the reef tended to be more choppy.

3. EXPERIMENTAL

The equipment used to measure IR, broad-band transmission at the tropical site was essentially the same as that used for previous temperate site measurements(ref.4). References 4 and 5 provide a description of the equipment used and only a brief description will be given here. The transmissometer consisted of a trailer-mounted black-body source and a van-mounted radiometer. Figure 4(a) shows the location of the trailer on the island while figure 4(b) shows the location of the receiver van at the shoreline. Using selected filter/detector combinations in the radiometer, maximum sensitivity could be attained for a particular spectral region. Both the source and receiver are calibrated to allow absolute measurements of effective transmission to be made for the combined source/filter/detector spectral response. The spectral regions defined by the filter half power points are given in Table 1. At selected times, surface temperature measurements of the cavity were made to check the calibration of the source. The day-by-day performance of the source was monitored with several internally mounted thermocouples. Any receiver drift or malfunction was checked before and after each measurement period using an internal chopped source which could be rotated into the field of view of the receiver. An estimate of the uncertainty in the transmittance measurements is given in Appendix II of reference 4.

TABLE 1. SPECTRAL REGIONS SELECTED FOR COWLEY BEACH MEASUREMENTS

Filter No.	Half power points (μm)	Filter No.	Half power points (μm)
1	1.48 - 2.50	8	4.41 - 5.41
2	1.44 - 1.82	10	8.20 - 11.80
5	3.55 - 4.00	11	8.33 - 9.80

The meteorological parameters, air temperature, relative humidity, visibility, sea state, wind speed and wind direction were recorded every ten minutes during intensive measurement periods lasting nominally two weeks. Air temperature and humidity measurements were made at each end of the path while the remaining parameters were measured at the shore end of the path. In addition, measurements were made on the total particle number density and radon count, which give information on the type of air mass present at the site. During some of the measurements a PMS optical array probe combined with a high volume aspirator was used to obtain data on the large particles (10 to 90 μm diameter) mainly arising from surf action on the beach.

4. RESULTS

This report covers data collected on 68 days during the period March 1982 and October 1983. Generally the equipment was operated for a two week period (weather permitting) by Electronics Research Laboratory (ERL) personnel and thus comprised the bulk of data. In between these periods JTTRE personnel operated the equipment to supplement the database. Data collected for high water vapour pressures were restricted to the latter part of the wet season (ie March) as January and February are the two wettest months which made it very impractical to conduct transmission measurements at that time. Most data

were collected from the period 1100 to 1500 h when the smoke from cane burning during the months between July and November had by that time dispersed from the site. Essentially the same approach was taken on the data reduction as described in reference 4, where 3 min averages of the radiometer signals were used.

All the data were stored and sorted on the IBM 370/3033 mainframe computer. In this report transmittance data are only presented which have been sorted separately for three meteorological parameters (temperature, absolute and relative humidity). For the four filters in the 3.5 to 12 μm region, the transmission data were averaged within 0.5 g/m^3 intervals of water vapour concentration and plotted against this parameter. In the 1.5 to 2.5 μm region the transmission data measured for the two filter bands were averaged within 5% relative humidity intervals and plotted. For these relative humidity plots, wind direction was restricted to 25 to 200°, generally ensuring that a maritime aerosol was present. The results are presented in figures 5 to 17; experimental data are plotted as a dot/bar complex, the dots representing the mean of the averaged transmittance over the interval, and the bars representing the extreme transmittances. The solid and dot-dashed curves represent LOWTRAN 6 predictions using the Navy and Standard Maritime aerosol models, respectively.

The LOWTRAN 6 transmittance calculations were convolved by numerical integration with the source and filter/detector responses as described in Appendix I of reference 4 to given an effective transmittance. These calculations were done for the meteorological conditions under which the data in the figures were sorted, and plotted as lines on the same figures. Since the predominant absorber in the 8 to 12 μm region for long ranges and high humidities is the water continuum component, the effective transmittance can be assumed to closely follow a quadratic relationship with the water vapour concentration (ρ) because the water continuum absorption is based on a quadratic function of ρ. In figures 5 and 6 where the data for all temperatures have been combined for each of the two filters, a least squares quadratic fit was made to the data to clearly show the quadratic dependence over the full range of ρ. These two curves are plotted as dashed curves in the figures. (The temperature dependence of transmittance over the range of 20 to 30°C is not expected to be more than several percent and the aerosol extinction will also not be a large factor as visibilities were mostly between 40 and 120 km.)

5. DISCUSSION

5.1 Atmospheric transmittance in 8 to 12 μm region

The comparison of the experimental transmission data and LOWTRAN 6 predictions given in figures 5 to 8, reveal a substantial discrepancy. The possibility that such a discrepancy exists in this window has been revealed by Ben-Shalom et al in their long path, low resolution transmission measurements(ref.6). An error in the calibration of the equipment would only alter the transmittance by a constant factor, whereas the discrepancy here is not constant with ρ. From figures 5 and 6, the factor ranges from about 1.5 at 12 g/m^3 to 2.9 at 22 g/m^3, indicating a substantial increase in the discrepancy at the higher values of ρ. Thus a calibration error can at the most only make a partial contribution to this difference. The local water line absorption for this region is represented in LOWTRAN by a single parameter band model and has been found to compare well with FASCODE 1C predictions. Also it does not predominate as an absorber in the way water continuum does and exhibits a linear dependence on ρ. Hence, one has to look to the other source which could contribute to this discrepancy, namely, the water continuum absorption coefficient, $K_c(\nu)$.

The continuum contribution to the total water absorption is given by

$$K_c(\nu) = \rho_s \nu \tanh\left(\frac{hc\nu}{2kT}\right)\left[\left(\frac{\rho_s}{\rho_o}\right) C_s^\circ(\nu,T) + \left(\frac{\rho_f}{\rho_o}\right) C_f^\circ(\nu,T)\right] \quad (1)$$

where T is the temperature (K), ν the wavenumber (cm^{-1}), $hc/k = 1.43879$ K/cm^{-1}, (ρ_s/ρ_o) and (ρ_f/ρ_o) are the number density ratios for the self and foreign continuum(ref.2). The quantity, ρ_o, is the reference number density defined at 1013 mb and 296K. The semi-empirical theory used for the water continuum absorption model has divided the coefficient into two components, namely self ($C_s^\circ(\nu)$) and foreign broadening ($C_f^\circ(\nu)$) which covers collision broadening between water-water and water-nitrogen molecules, respectively. The $C_s^\circ(\nu)$) values dominate the water continuum absorption as the values of $C_f^\circ(\nu)$ are generally three orders lower. (It should be noted that the water continuum model used in LOWTRAN 6 has been changed from the one used in previous versions of LOWTRAN where the absorption coefficient was derived purely from an empirical relationship based on Burch's data(ref.8)).

The $C_s^\circ(\nu)$ and $C_f^\circ(\nu)$ values of the LOWTRAN 6 water continuum model(ref.2) for 296K have been derived over the 0 to 1200 cm^{-1} region by modifying the water vapour line shape based on the impact approximation theory(ref.7). This modification to the line shape theory includes an empirical function since the original impact theory predicts low $C(\nu)$ values in the 0 to 500 cm^{-1} region and high values in the 1000 cm^{-1} window. The modified expression includes parameters which are adjusted to fit the Burch absorption data at 0 cm^{-1} and between 300 and 1200 cm^{-1}. The agreement between the calculated and experimental data appears reasonable but since the modification is basically empirical it could still reflect any absolute errors in the experimental data. (It should be noted that transmission predictions at high humidities by the LOWTRAN 6 code with a maritime aerosol model using the input conditions presented for figures 5 to 8 are slightly lower than LOWTRAN 5 predictions).

5.1.1 Effect of errors in water continuum absorption coefficients on transmission

The extent that errors in $C_s^\circ(\nu)$ can have on the water continuum absorption is revealed in figure 9. It shows changes to the LOWTRAN water continuum transmittance in the 8.7 to 11 µm region for a -10% (dashed curve) and -25% error (dot-dashed curve) in $C_s^\circ(\nu)$ over a 7 km range for two water vapour contents at T=25°C. The solid curve represents the normal LOWTRAN water continuum transmittance. Table 2(a) summarises the factor by which the two errors selected above increase the continuum transmission at three wavenumbers. These values indicate a dramatic sensitivity of the water continuum absorption to experimental errors in the self-broadening coefficients. Thus for long paths and high water vapour contents the change in continuum transmission can be in excess of 50% for only a 10% reduction in $C_s^\circ(\nu)$ thereby indicating that Burch's ±10% estimate of the error in the experimental data could very well be responsible for a significant error in the transmittance. For the situation where water vapour contents fall within 8 to 12 g/m^3, eg the Victor Harbour (VH) and San Nicolas Island(ref.9) data, the

influence of the error is not quite so great (Table 2(b)). Thus any trend in the data for the lower water vapour contents may be hidden if the transmission measurements have an estimated overall uncertainty comparable with this change.

5.1.2 Estimation of correction to water continuum absorption coefficients

Assuming for the present that an error in calibration of the equipment in the 8 to 12 μm region does not contribute to the discrepancy, an estimate of the error in $C_s^\circ(\nu)$ can be established. If the $C_s^\circ(\nu)$ values for 296K are reduced by a factor of 0.6 (independent of wavenumber), then the LOWTRAN 6 predictions using the Navy aerosol provided a reasonable fit to the data for the filters 10 and 11, as shown by the dashed curve in figures 7 and 8. Although the differences in using the two aerosol models are small, the Navy aerosol was chosen with an air mass character number of 2, as this best represented the open-ocean air mass present. (A radon counter was used to monitor the air mass type).

Predicted transmission data using the 0.6 factor in LOWTRAN 6 were also applied to the Victor Harbor 8 to 12 μm data given in reference 4. These data (represented by the dash curve), are reproduced in figure 10 along with the original LOWTRAN 6 prediction (solid curve) using the Navy aerosol. Again, in spite of the much smaller discrepancy, there is generally an improvement in the fit to the experimental data.

Errors as implied above in the $C_s^\circ(\nu)$ coefficients for the continuum absorption model in LOWTRAN could be attributable to a combination of

(1) measuring the coefficients absolutely using a multipass cell, and

(2) taking the best empirical fit to the data.

An error could also arise in the multipass absorption data, if an inadequate estimation of the local water line absorption has been made(ref.10). The latter error may result from using too small a bound placed on the water lines contributing to the absorption at a particular wavenumber although it is not expected that this error would be any more than several percent.

One should also note that the values of $C_s^\circ(\nu)$ are becoming smaller as one goes from 800 to 1200 cm^{-1}. If a multipass cell with an effective pathlength of ~500 m is used to measure these coefficients, this technique can exhibit sensitivity limitations and as a result the errors could increase. Maximum water vapour contents are generally limited to 15 g/m^3 because these cells are generally operated at room temperatures.

In the present work the errors in the measurement of the transmission mostly come from calibration of the transmissometer. The calibration uncertainty is estimated for 8 to 12 μm spectral region to be about ±8% (derived from error estimates given in Appendix II of reference 3). Thus the error implied in $C_s^\circ(\nu)$ chould in fact fall between -34% and -48%.

5.1.3 Review of recent water continuum absorption measurements

Since Burch made his water continuum absorption measurements in the early 1970's, several groups of workers have also reported measurements over the wavelength range 9.3 to 11.3 µm using systems with an optoacoustic detector and isotopic CO_2 laser sources(ref.11-15). The $C^0(\nu)$ values given in figure 11 and Table 3 were derived for a given temperature T, from the coefficients of the least squares fit for a curve of the form $A(\nu)p+B(\nu)p^2$ made to the original experimental absorption data provided in references 11 to 15. It has been shown(ref.12) that:

$$C_s^0(\nu) = p/w[B(\nu) + A(\nu)/P] \qquad (2)$$

where p is water vapour partial pressure(atmospheres),
P is total pressure(atmospheres), and
w is density of water vapour (molecules/cm^2).

For the comparison, only data from those laser lines whose wavenumbers fall well clear of local water absorption lines were considered, thereby minimising the local line contribution to the water absorption coefficient. This was done using the pictorial representation of the AFGL line compilation atlas.

Included also in the comparison are $C_s^o(\nu)$ coefficients calculated from the LOWTRAN 5 continuum model at 296K which in effect represents the best fit to the Burch data. (Note that the LOWTRAN 5 equation was fitted to the Burch data over the frequency range 800 to 1200 cm^{-1}(ref.8). The data of both Shumate et al and Loper et al recorded at 300K were corrected for the temperature effect using a negative temperature coefficient of 2%/°C, (determined using the LOWTRAN interpolation for this wavelength region, which it should be noted is about half the value estimated from figure 8 in reference 12 for the temperature region of 300K to 283K). The $C_s^o(\nu)$ values in figure 11 indicate that the more recent data are widely scattered with respect to the Burch data and the uncertainty in $C_s^o(\nu)$ values is noticeably much greater than ±10%.

Shumate et al(ref.13) reported in their work that continuum absorption data are up to 15% lower than Burch data as water vapour pressures approach 20 torr. These workers highlighted the drastic dependence of the size of the quadratic term B(ν) on measurement errors as water vapour pressures become high, when the experimental absorption data away from local line absorption are fitted to the curve of the form $A(\nu)p + B(\nu)p^2$: The authors implied that the spectrophone technique is an inaccurate method of measuring continuum absorption. The large scatter revealed in the published spectrophone-determined $C_s^o(\nu)$ coefficients referred to above, supports this comment.

The work of Loper et al(ref.12), also reports on the negative temperature dependence of water continuum in the 10.2 to 10.7 µm region between 300K and 263K. Their temperature coefficient results appear to be more consistent with the negative temperature dependence of continuum absorption observed for a water vapour dimer model for temperatures below 373K, while the collisional broadening continuum model with its weak positive temperature coefficient appears to be more appropriate for

temperatures above 373K. The temperature coefficient as mentioned earlier for the 300 to 283K temperature interval is approximately double that used in the LOWTRAN model. This decrease, it if were true, would have serious implications in slant path transmittance predictions for the lower atmosphere, where temperature generally has fallen by about 10K at the boundary layer (~2 km).

5.2 Atmospheric transmittance in 3.5 to 5.5 μm region

The transmission data plotted against absolute humidity in the spectral regions 3.55 to 4.0 and 4.41 to 5.41 μm (figures 12 and 13), were restricted to maritime conditions, and compared with the predictions of LOWTRAN 6. Since the influence of temperature on transmittance is not as strong in these regions as is evident in 8 to 12 μm region, data were not sorted into separate temperature groups. In these two spectral regions the predicted data show reasonable agreement with the experimental data as distinct from the comparison reported in the 8 to 12 μm region above. The agreement in the 4.4 to 5.4 μm region has reaffirmed earlier results(ref.4) which at the time indicated the need to extend the water continuum model in LOWTRAN to this region. Following the inclusion and current verification of this modification to LOWTRAN, more confidence is now attached to LOWTRAN's predictions for high water vapour concentrations and long pathlengths in the 4.5 to 5.5 μm region.

5.3 Atmospheric transmittance in 1.5 to 2.5 μm region

In this region the transmission data have been grouped into two temperature and two visibility groups and the transmittance data then averaged within each 5% RH interval. Figures 14 to 17 reproduce these transmittance data plotted against relative humidity for each of these groups covering 1.44 to 1.83 μm and 1.48 to 2.5 μm spectral regions. Again wind directions were restricted to 25 to 200°, which represent maritime conditions.

In comparing the data with the LOWTRAN 6 predictions, both the Maritime and Navy aerosol models have been used. The Navy aerosol model predicts a lower extinction than does the Standard Maritime aerosol model (which is the same model used in LOWTRAN 5). The difference between the two becomes greater when water vapour contents are below about 20 g/m^3. The Navy aerosol which represents an open-ocean maritime environment uses 3 size distributions to build up a composite distribution, namely distributions for the continental (0.01 to 0.3 μm), stationary marine (0.3 to 2.0 μm) and fresh marine or large particle (2.0 to 15 μm) aerosol components. In high visibility situations there is a greater contributing fraction of large particles to the overall size distribution relative to the continental component which results in increased extinction, particularly at the longer wavelength.

The comparisons shown in the figures reveal that the degree of fit ranges from good to fair which means one can only say that for this region the model predictions are reasonable and do not exhibit a disproportionate error. However, the choice of using either the Navy or Maritime aerosol model in these comparisons is indecisive.

Recent overseas measurements(ref.16), have shown that the Navy model predictions for particle numbers above 2 μm radius are not adequate. The particle numbers in this size region exhibit a strong dependence on wind speed (ie, sea state) and it is felt the model does not adequately reflect the effects that the wind has in generating the large particles. For the smaller particle concentrations, the Navy aerosol model predictions appear to be more reliable, particularly if the airmass type is monitored with radon and total particle counters, as was done in this work.

6. CONCLUSIONS

IR transmission data have been reported for six broad-band spectral regions from 1.5 to 12 µm for a 7 km path in a coastal maritime environment where high water vapour pressures prevailed. The data suggest that there is a disagreement between the measured transmission data and that predicted by LOWTRAN 6 for the 8 to 12 µm region. Even allowing for calibration uncertainty in the measured data, the discrepancy can be explained by the presence of moderate negatively biased errors of the order of 35 to 45% in the water continuum self-broadening absorption coefficients. The extent of the magnitude of the error in these coefficients for high water vapour pressures has been revealed to strongly influence the water continuum transmission. This is to say that the ±10% error estimated by Burch et al(ref.3) for their measurements of the coefficients in the 8 to 12 µm waveband has a profound effect on transmission at long ranges and high water vapour pressures and thus produces an overall error which falls well outside the general LOWTRAN model uncertainty of ±10%. A review of more recent data on continuum absorption obtained using optoacoustic techniques indicates that an uncertainty still exists in the absorption coefficients. However, it has recently come to the author's attention(ref.17) that Burch has remeasured the self-broadening coefficients for the 8 to 12 µm region and as a consequence he has revised these values downwards by an amount of the order 25 to 30%. It is recommended that for improving the LOWTRAN model, in particular for assessing the temperature dependence of the absorption coefficients, that further experimental work be done to measure more accurately in the laboratory, the self-broadening coefficients over 8 to 12 µm region.

Within experimental and model uncertainties, reasonable agreement was found between the experimental and predicted transmission data in the 3.5 to 5.5 µm region, particularly in view of the fact that water continuum absorption has been included in the 4.4 to 5.4 µm region.

For the 1.5 to 2.5 µm spectral region, it can be concluded from these comparisons that there is generally reasonable agreement. Due to the low aerosol loading generally prevailing during all the measurements reported here (ie the aerosol extinction was not significantly large), no clear distinction could be made on the choice of using either the Navy or Maritime aerosol model. Even despite the inadequacy in the large particle, wind dependent size regime, the Navy aerosol model at this stage probably best represents the aerosol extinction prevailing during the measurements, particularly for the small particles contributing to the extinction.

7. ACKNOWLEDGEMENTS

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TABLE 2. RATIO OF CORRECTED TO UNCORRECTED WATER CONTINUUM TRANSMISSION AS FUNCTION OF WAVENUMBER FOR REDUCTIONS OF 25% AND 10% IN $C_s^\circ(\nu)$ VALUES

(a)

7 km 10 km	25% reduction		
	900 cm^{-1}	1000 cm^{-1}	1150 cm^{-1}
18 g/m^3	2.02 2.72	1.71 2.04	1.47 1.73
24 g/m^3	3.42 5.55	2.41 3.50	1.97 2.62
10% reduction			
18 g/m^3	1.32 1.49	1.22 1.33	1.17 1.24
24 g/m^3	1.64 2.00	1.41 1.67	1.31 1.47

(b)

5 km 9 km	25% reduction		
	900 cm^{-1}	1000 cm^{-1}	1150 cm^{-1}
8 g/m^3	1.12 1.22	1.08 1.15	1.06 1.11
12 g/m^3	1.27 1.52	1.18 1.35	1.14 1.26
10% reduction			
8 g/m^3	1.05 1.08	1.03 1.06	1.02 1.04
12 g/m^3	1.10 1.18	1.07 1.13	1.05 1.10

TABLE 3. SUMMARY OF MEASURED WATER CONTINUUM SELF BROADENING COEFFICIENTS FOR 296K AT SELECTED FREQUENCIES OF $^{12}C^{16}O_2$ AND $^{13}C^{16}O_2$ LASERS

Wave no (cm^{-1})	LOWTRAN 5 (Equation(4) in ref.8)	+Ryan et al(14)	*Loper et al(12)	*Shumate et al(13)	Peterson et al(ref.11)	
					Spectrophone	White Cell
I Band						
880.4	2.89×10^{-22}	2.32×10^{-22}				
893.4	2.73	4.02×10^{-22}				
903.7	2.61	3.00×10^{-22}				
933.9	2.32	3.03×10^{-22}				
942.2	2.54	8.26×10^{-23}				
942.38	2.25	3.62×10^{-22}	2.04×10^{-22}	1.64×10^{-22}	2.33×10^{-22}	
951.2	2.19	2.46×10^{-22}	2.16	1.94×10^{-22}	2.13×10^{-22}	
974.6	2.03	1.64×10^{-22}				1.69×10^{-22}
979.7	2.00	2.08×10^{-22}	1.96	6.64×10^{-23}		
983.25	1.98	2.75×10^{-22}	1.48	1.23×10^{-22}		
II Band						
987.0	1.96×10^{-22}	4.54×10^{-22}				
996.9	1.90	5.12×10^{-23}				
1031.1	1.75	1.76×10^{-22}				
1036.0	1.73	2.75×10^{-22}				
1046.9	1.69	6.08×10^{-23}		5.43×10^{-23}		
1048.7	1.68	1.41×10^{-22}		6.12×10^{-23}		1.56×10^{-22}
1082.3	1.58			4.14×10^{-23}		1.34×10^{-22}

(+) Original data were adjusted using the corrections given in reference 15.

(*) Data have been temperature-corrected from 300K to 296K (see text).

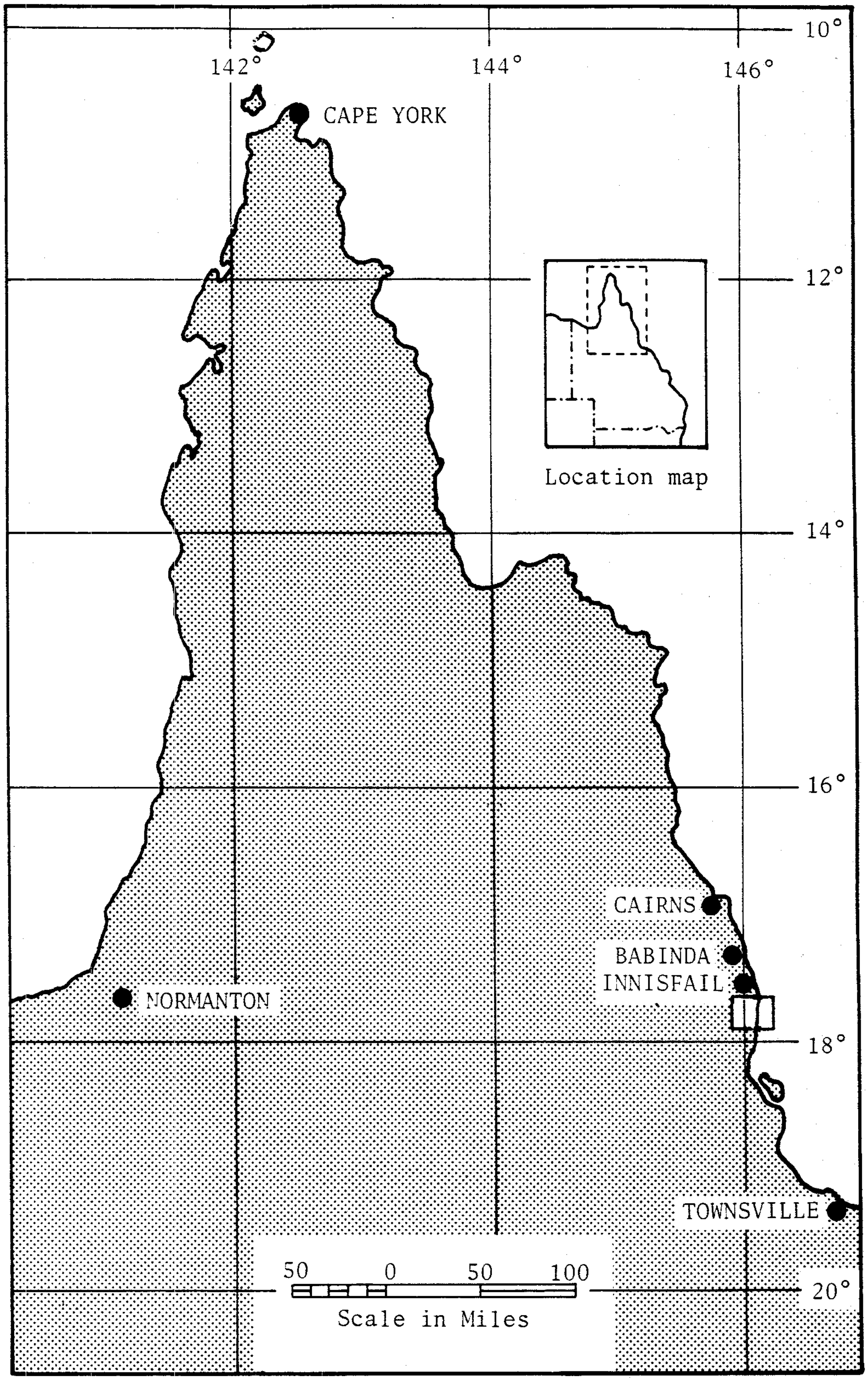


Figure 1. Location of the measurement site in Northern Queensland

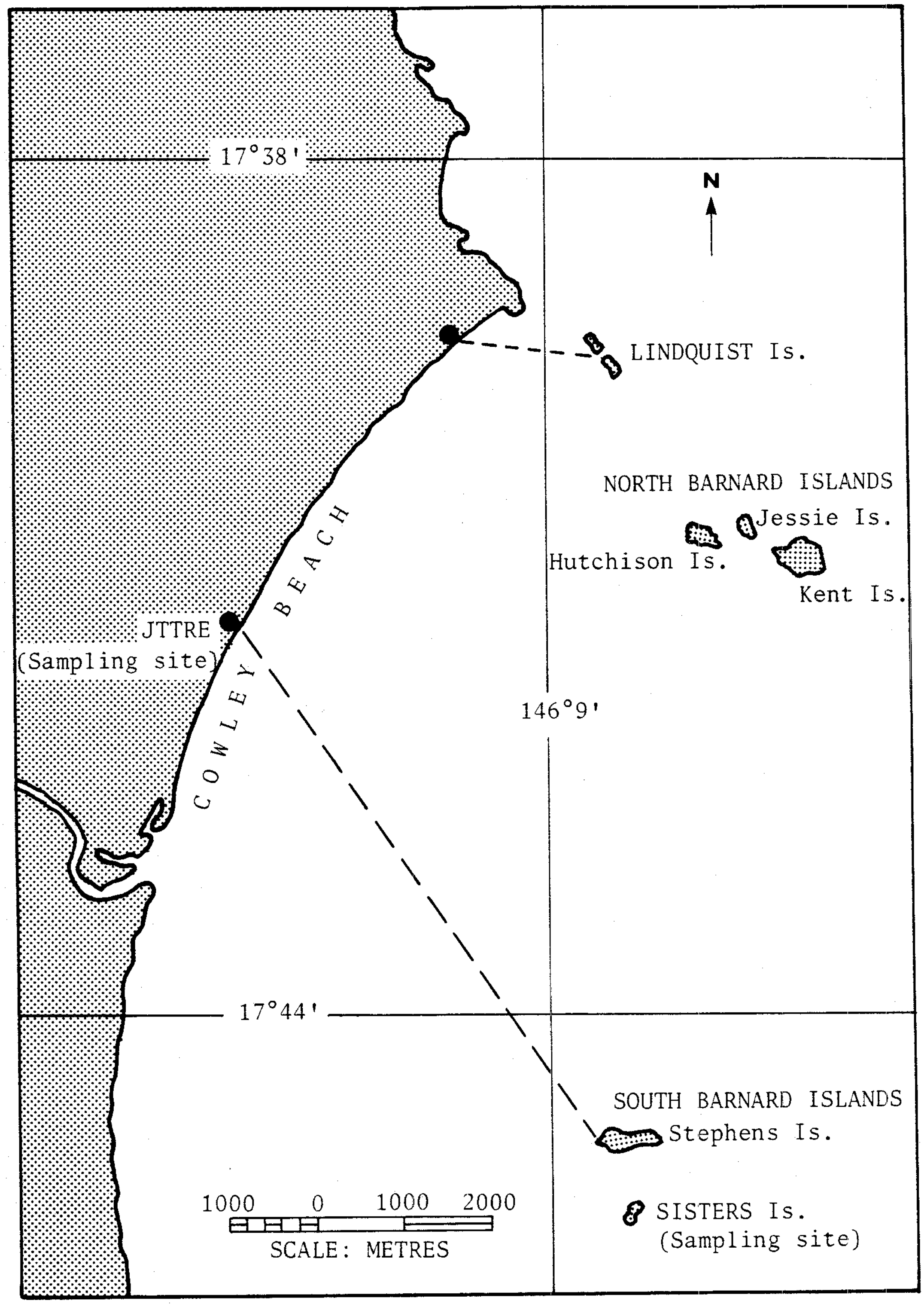


Figure 2. Transmission path location at Cowley Beach

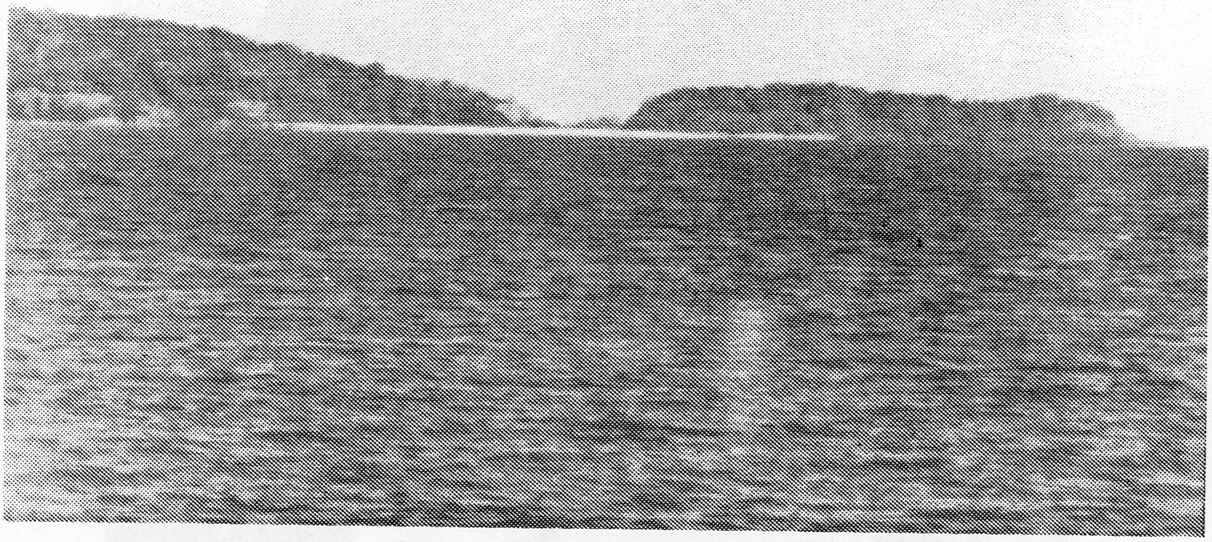
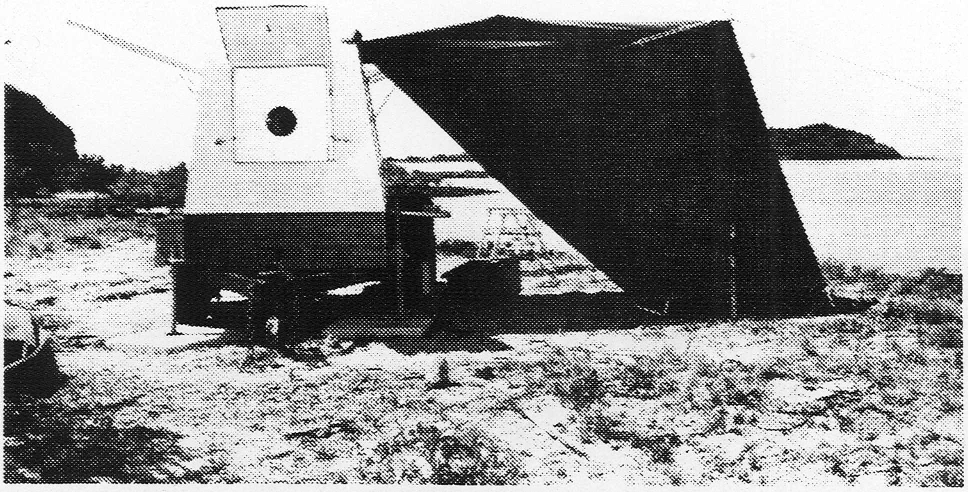
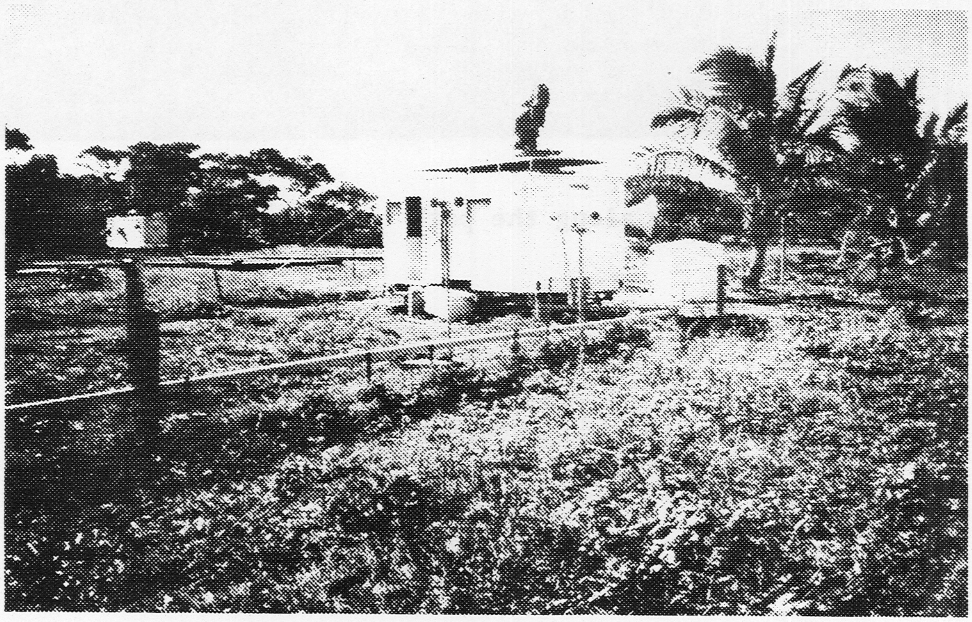


Figure 3. A view along the path towards Stephens Island



(a)



(b)

Figure 4. Photographs showing (a) the black-body source on the island and (b) the location of the receiver van on the shoreline

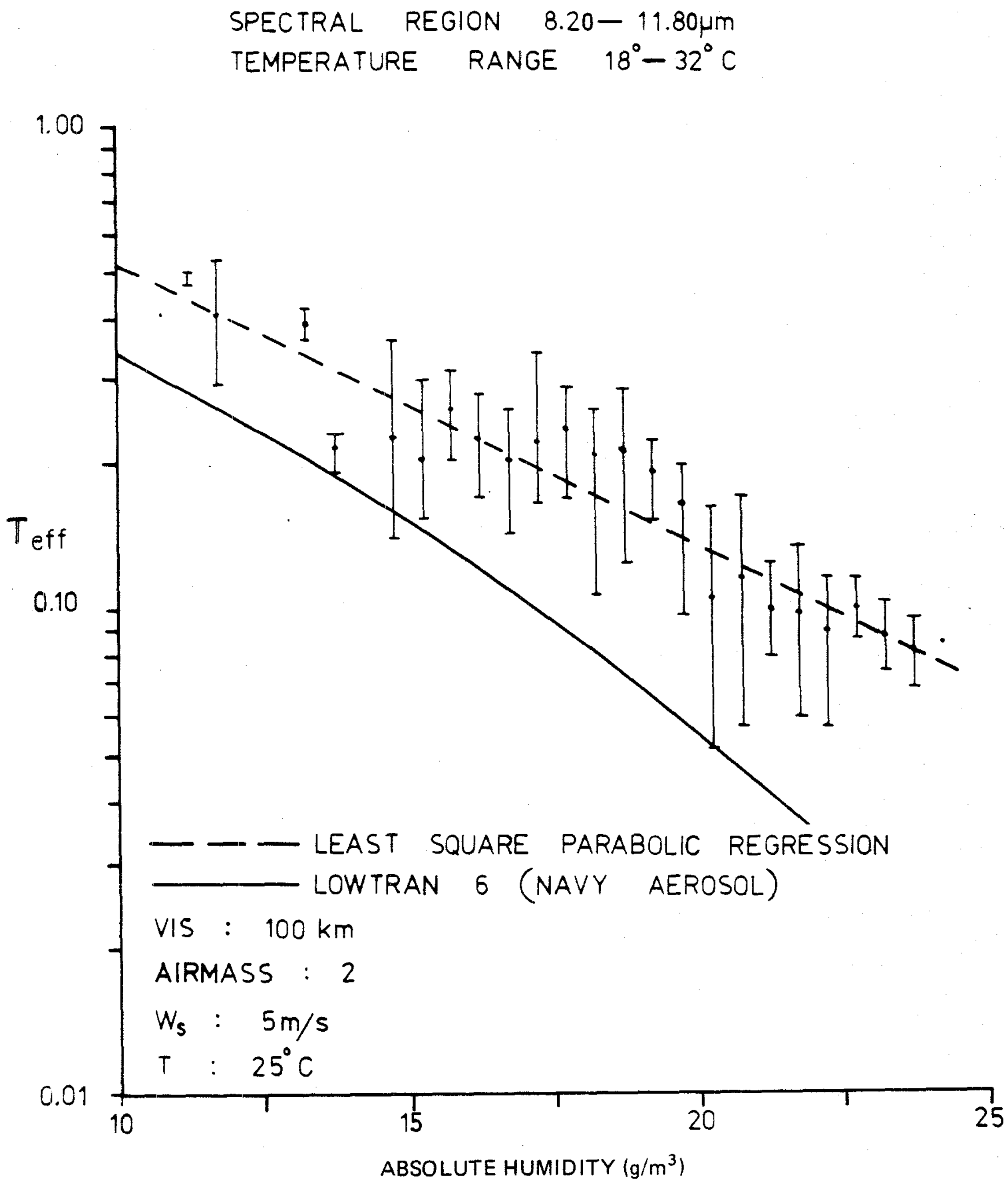


Figure 5. Variation of effective transmittance with absolute humidity in the 8.2 to 11.8 µm region for all temperatures

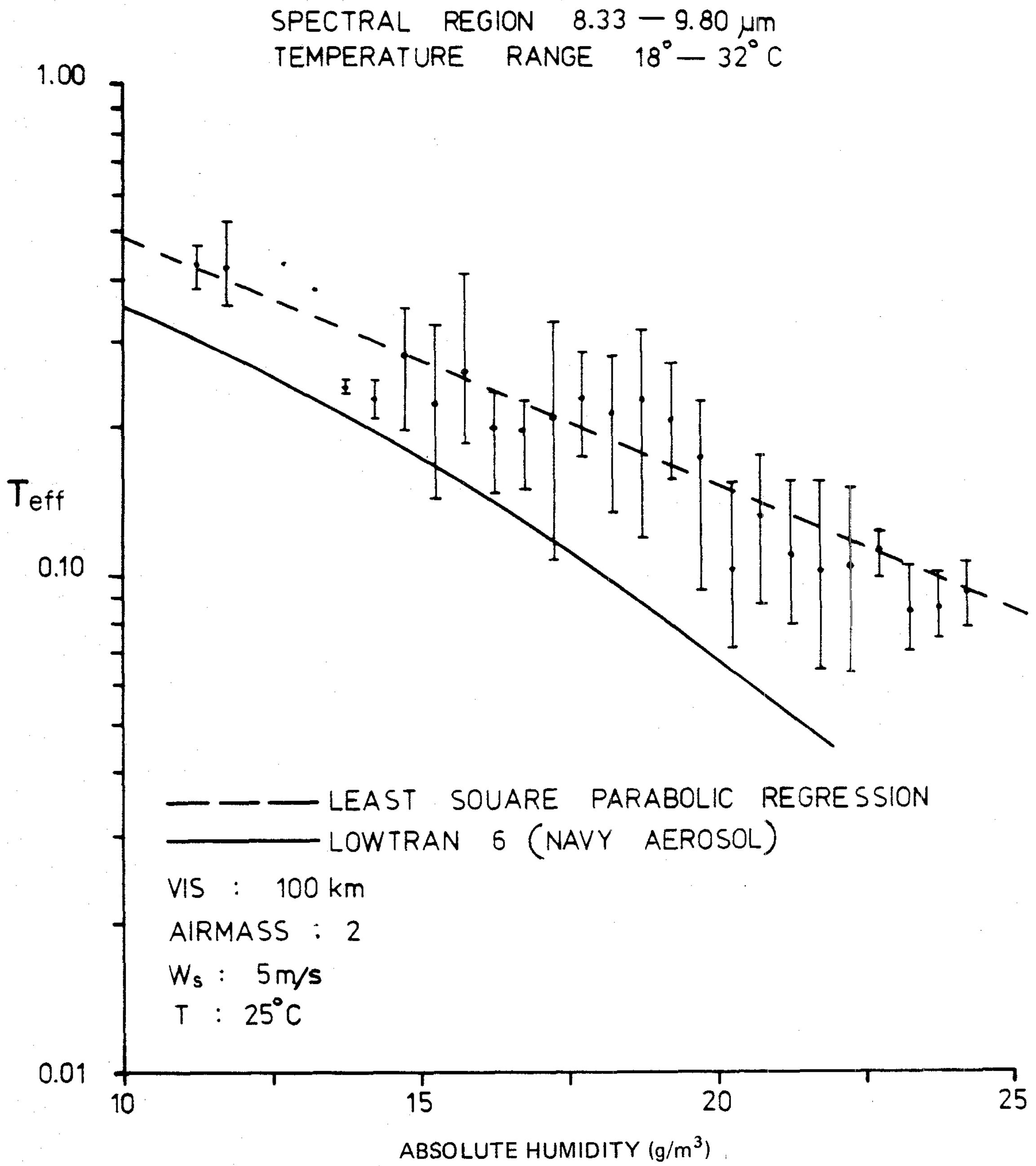


Figure 6. Variation of effective transmittance with absolute humidity in the 8.33 to 9.80 μm region for all temperatures

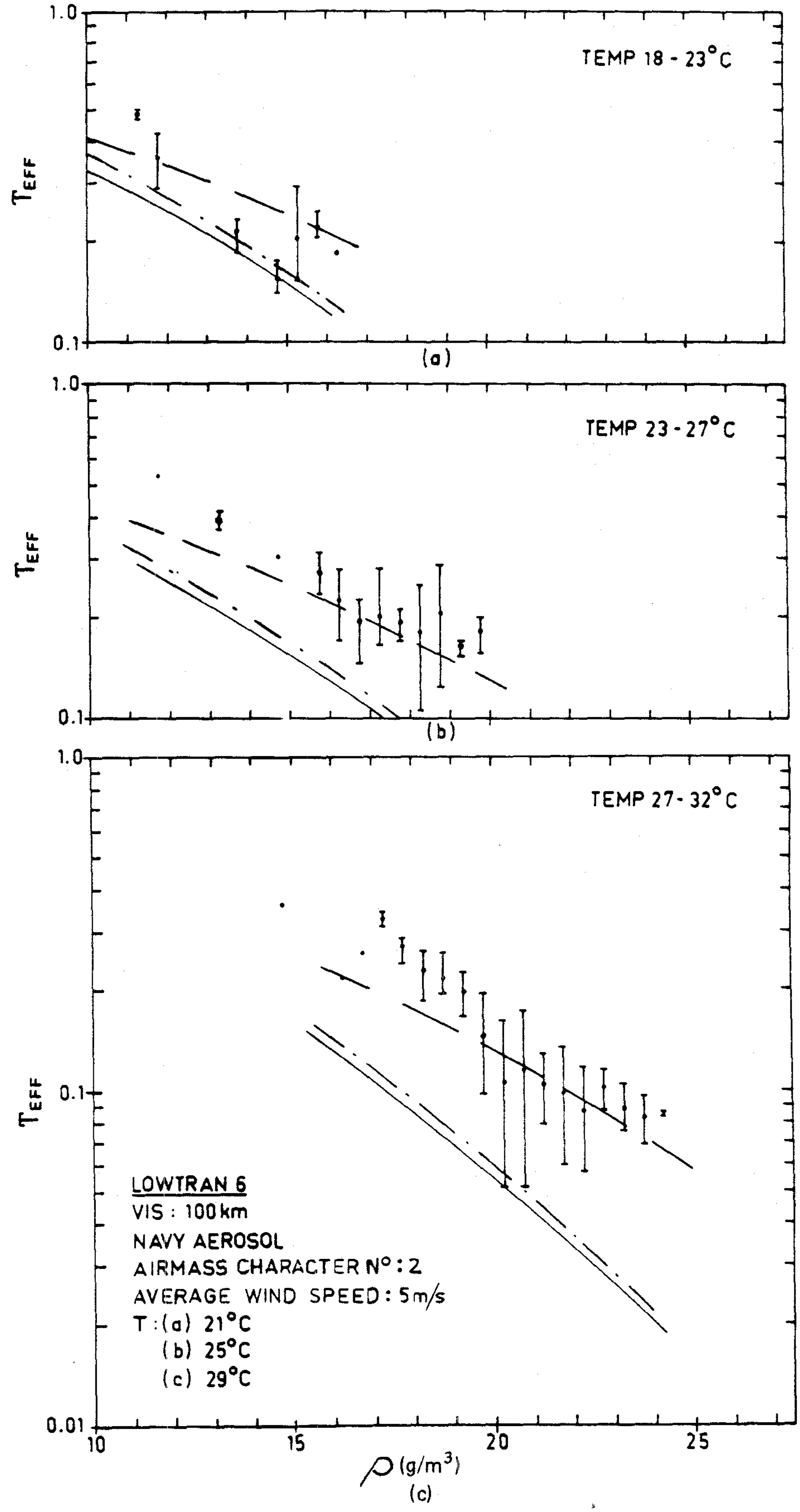


Figure 7. Variation of effective transmittance with absolute humidity in the 8.20 to 11.80 µm region for temperatures intervals (a) 18 to 23°C (b) 23 to 27°C and (c) 27 to 32°C

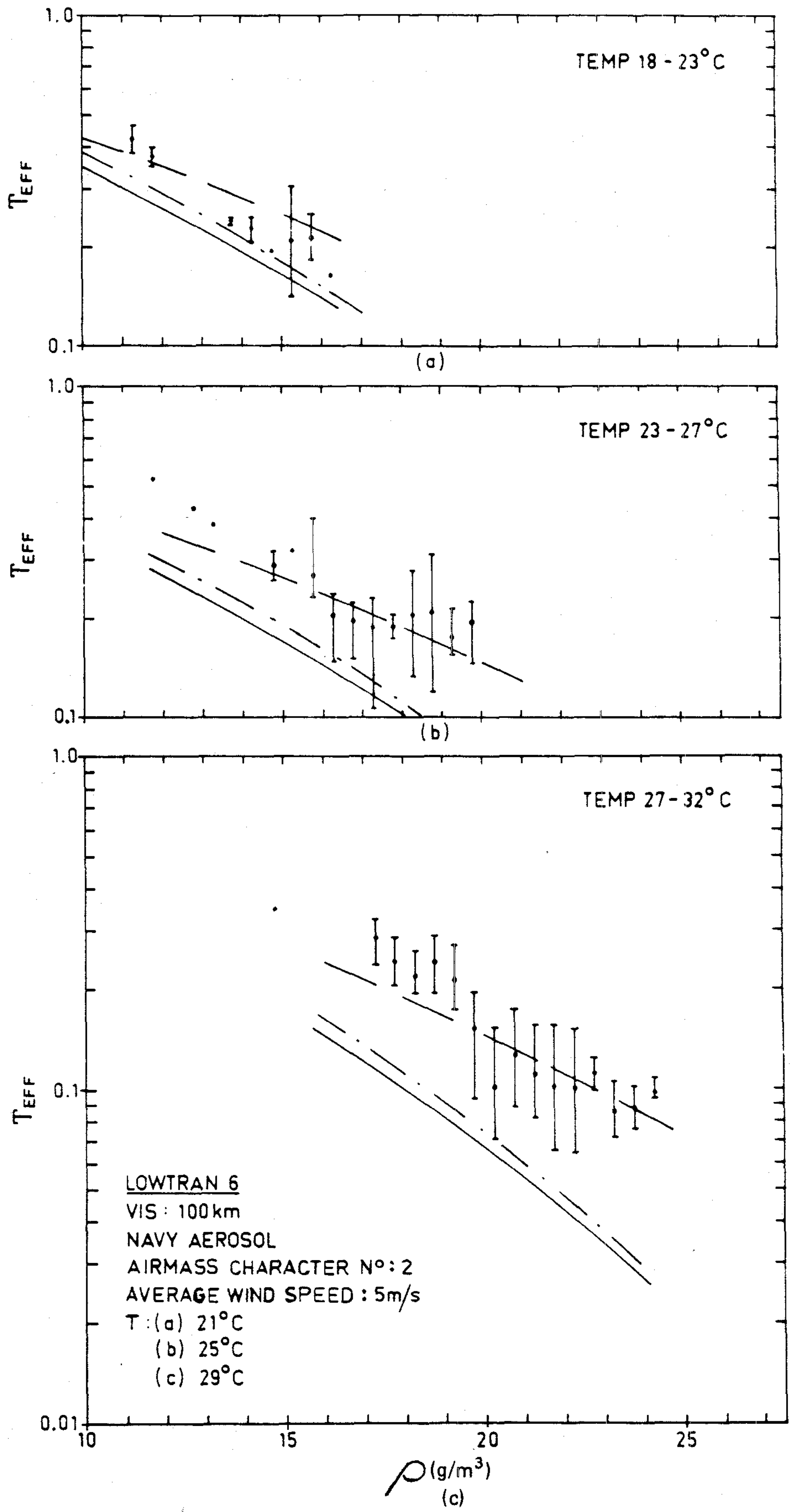
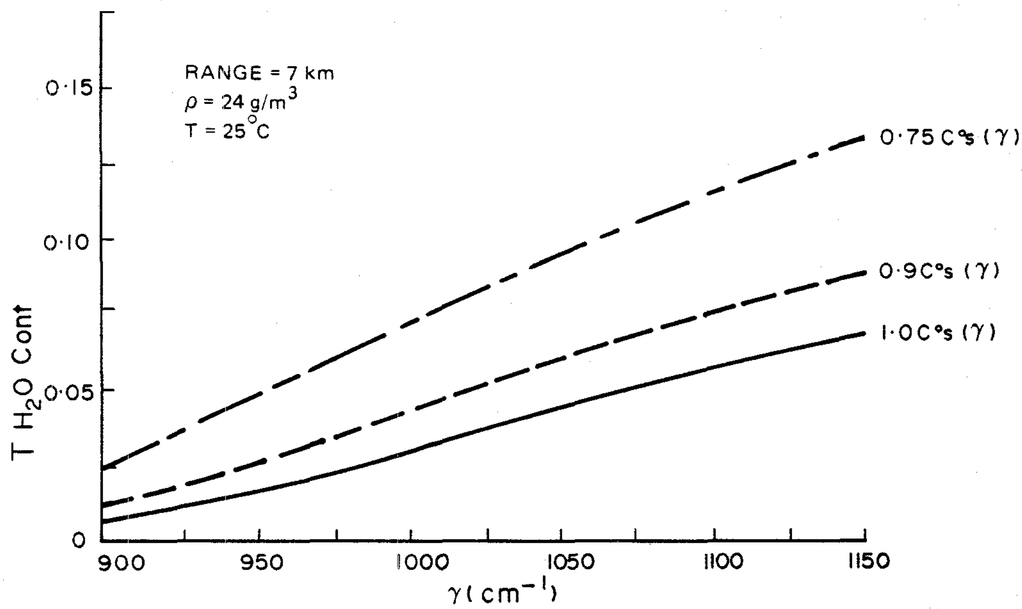


Figure 8. Variation of effective transmittance with absolute humidity in the 8.33 to 9.80 µm region for temperatures intervals (a) 18 to 23°C (b) 23 to 27°C and (c) 27 to 32°C



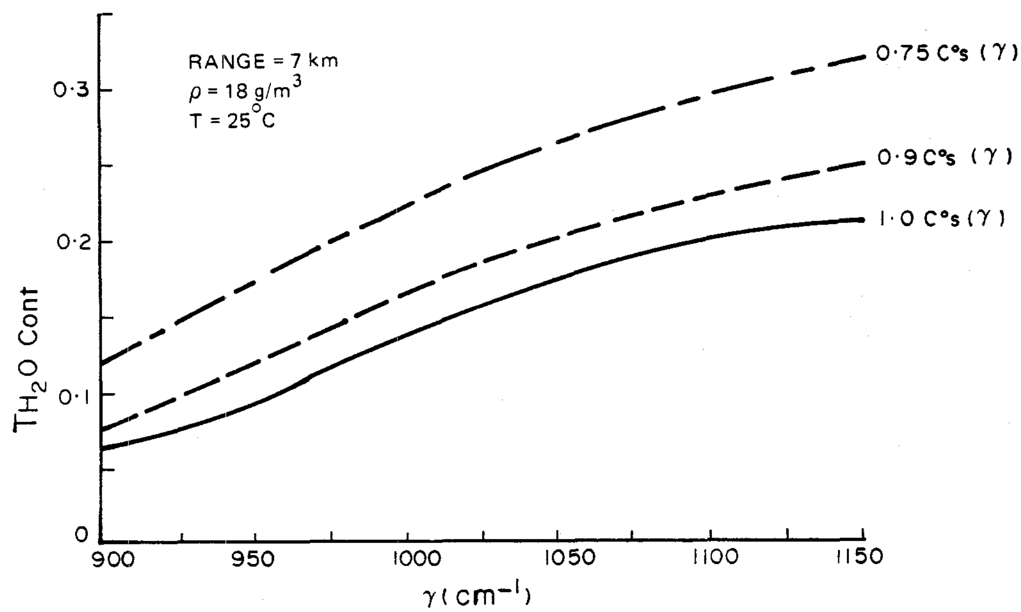


Figure 9. Effect of errors in self-broadening coefficient $C_s^\circ(\nu)$ on water continuum transmittance in 8.7 to 11.1 μm region

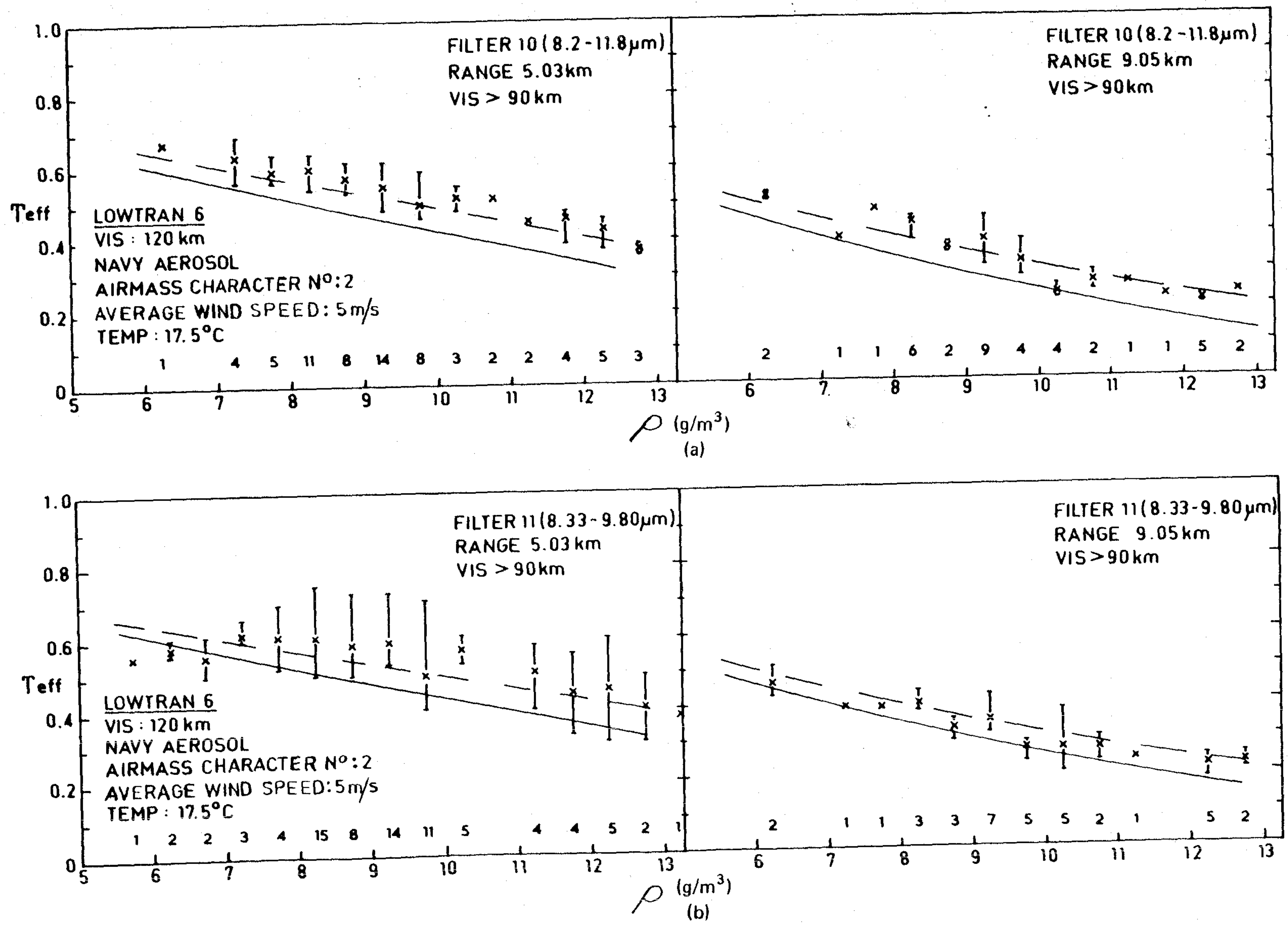


Figure 10. Variation of effective transmittance with absolute humidity as measured at Victor Harbor for (a) 8.20 to 11.80 μm and (b) 8.33 to 9.80 μm regions

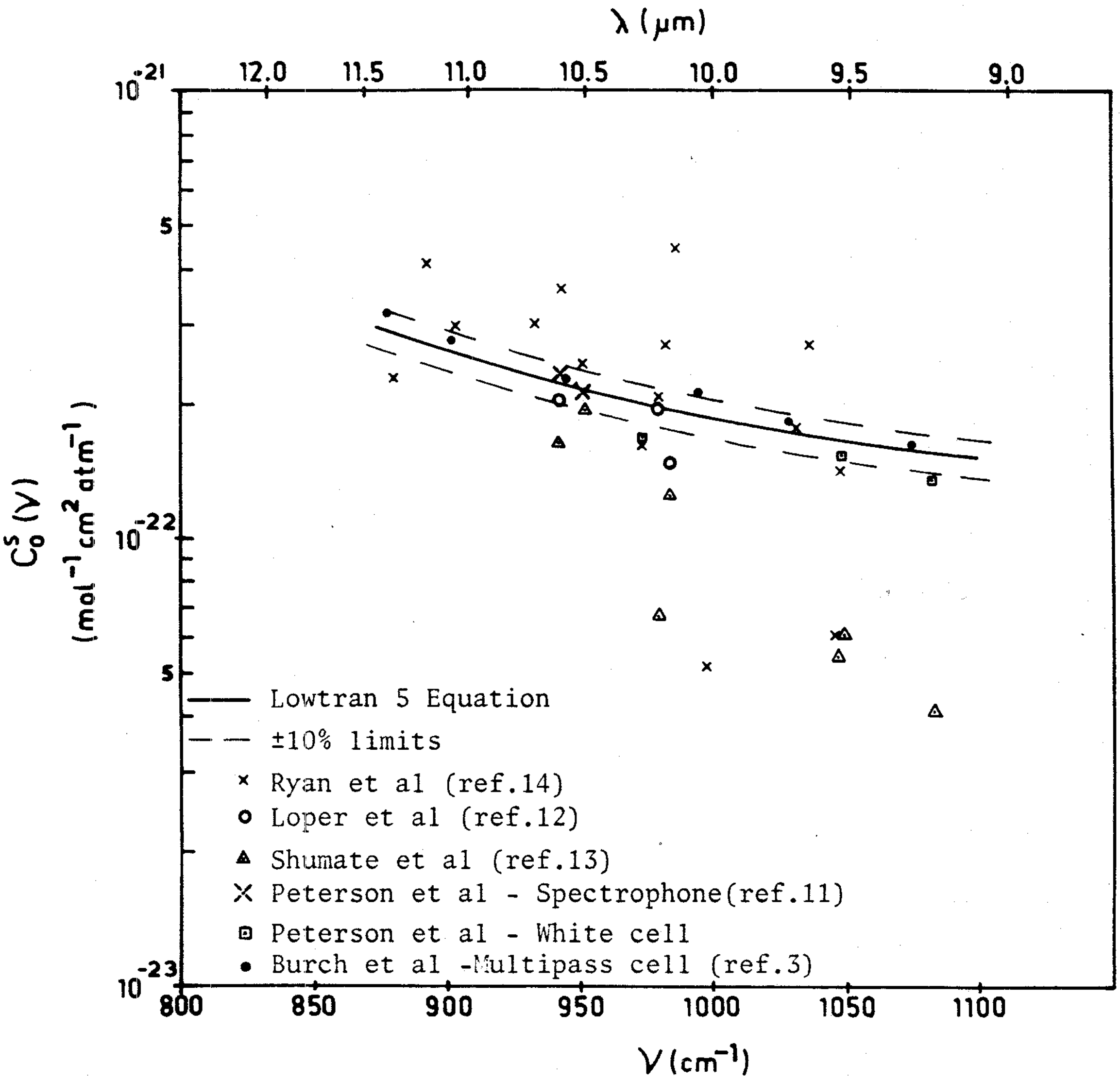


Figure 11. Experimentally reported water vapour continuum absorption coefficient data $C_s^{\circ}(\nu)$ versus wavenumber at 296K

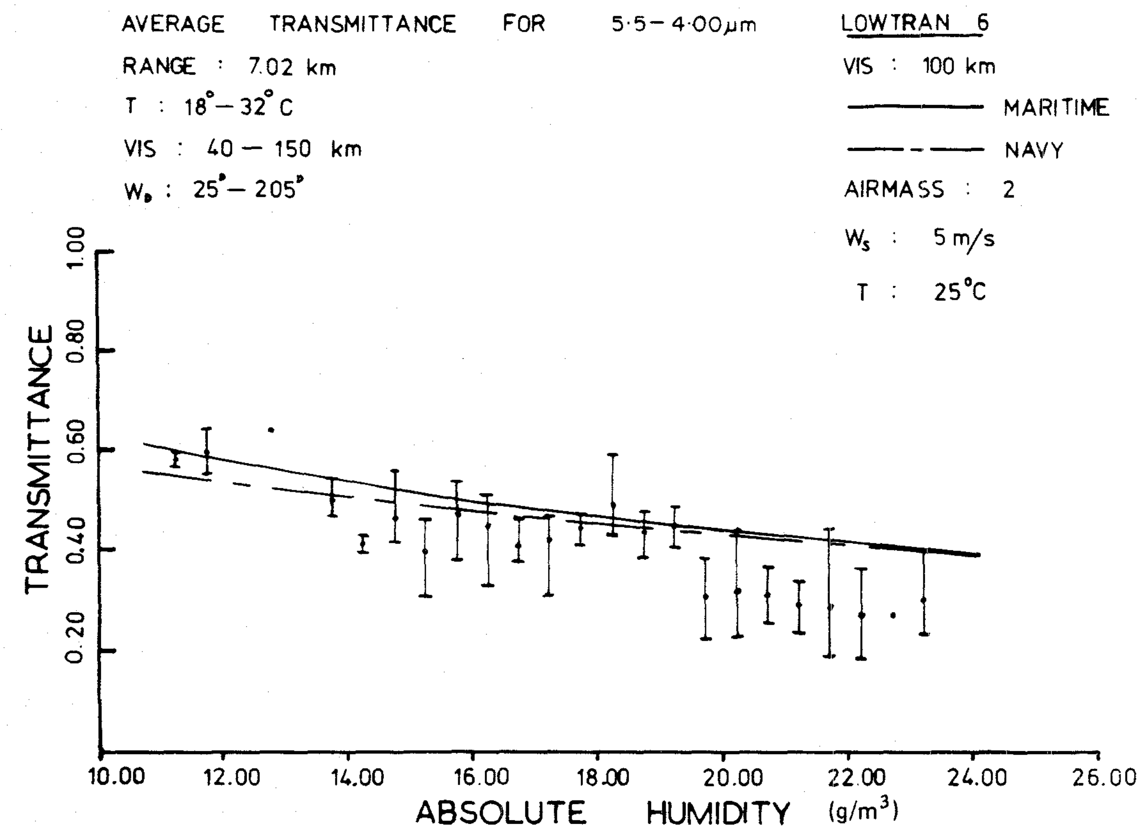


Figure 12. Variation of effective transmittance with absolute humidity in the 3.55 to 4.00 μm region for all temperatures

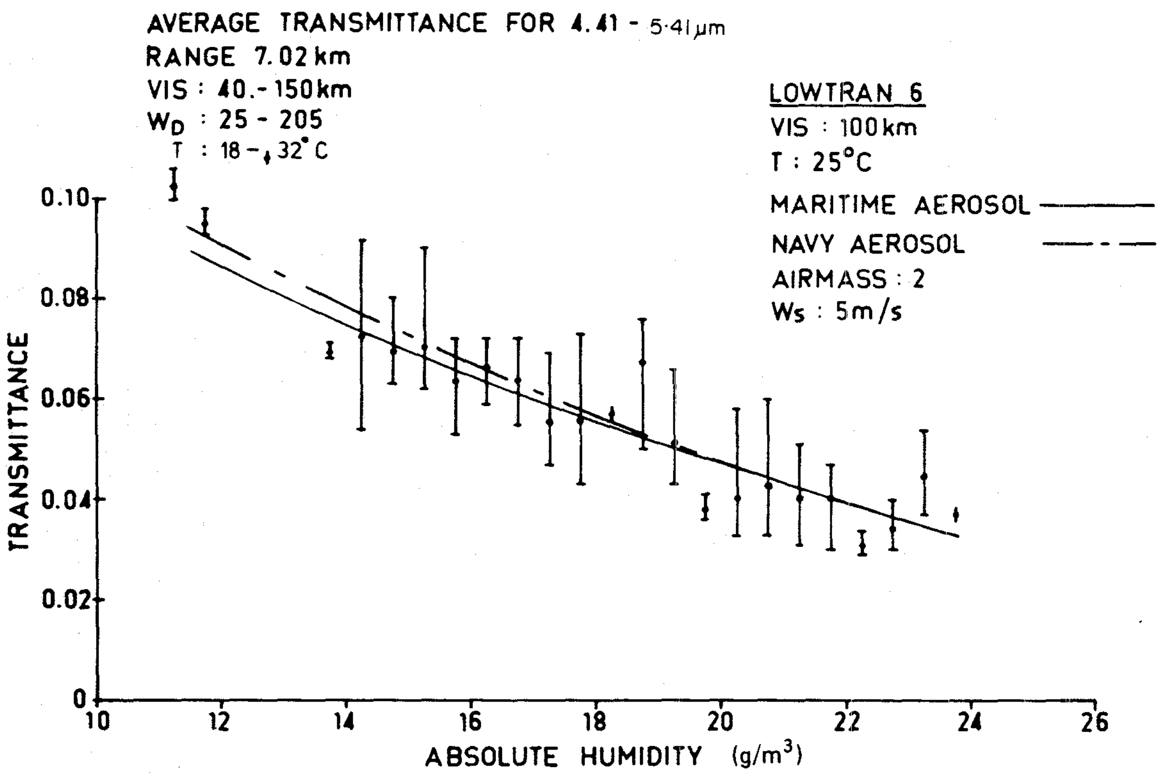
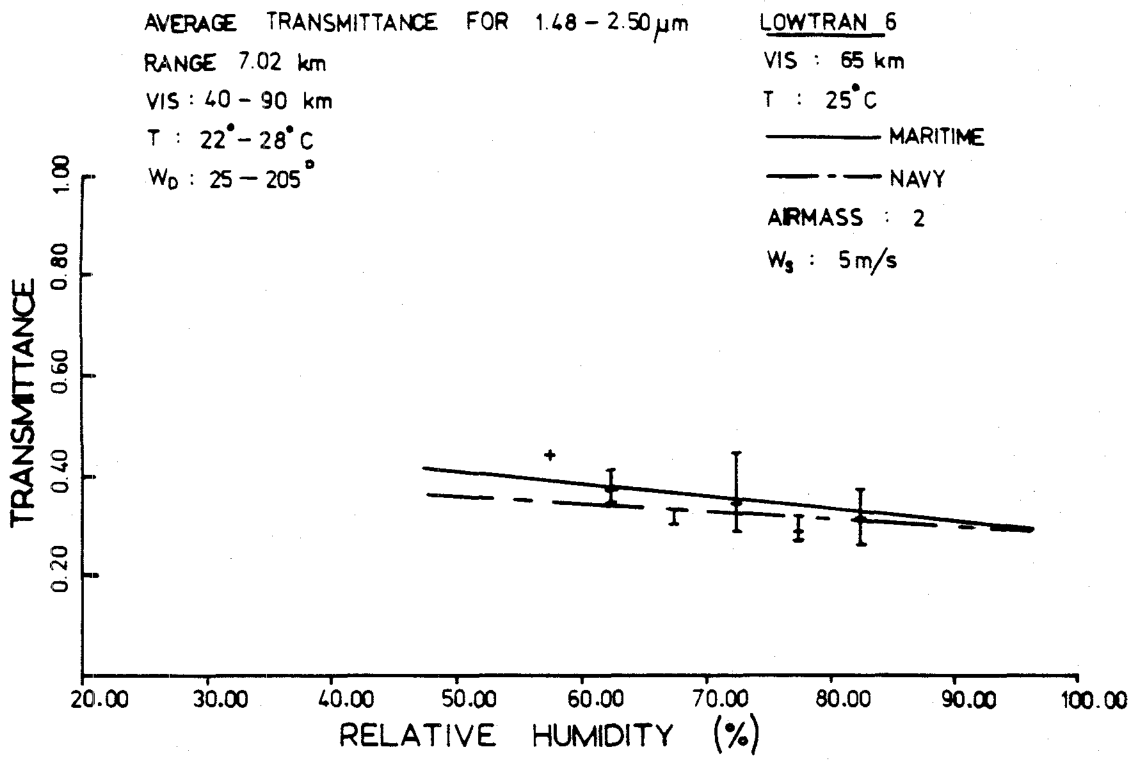
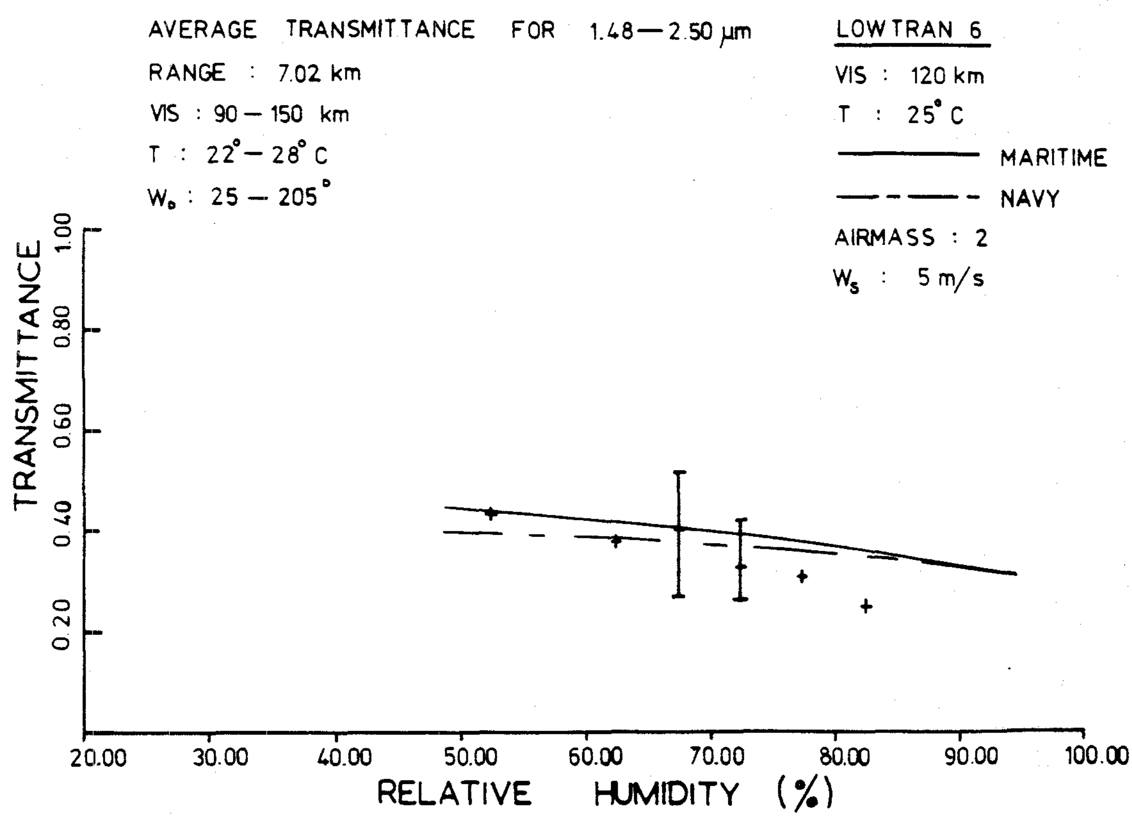


Figure 13. Variation of effective transmittance with absolute humidity in the 4.41 to 5.41 μm region for all temperatures

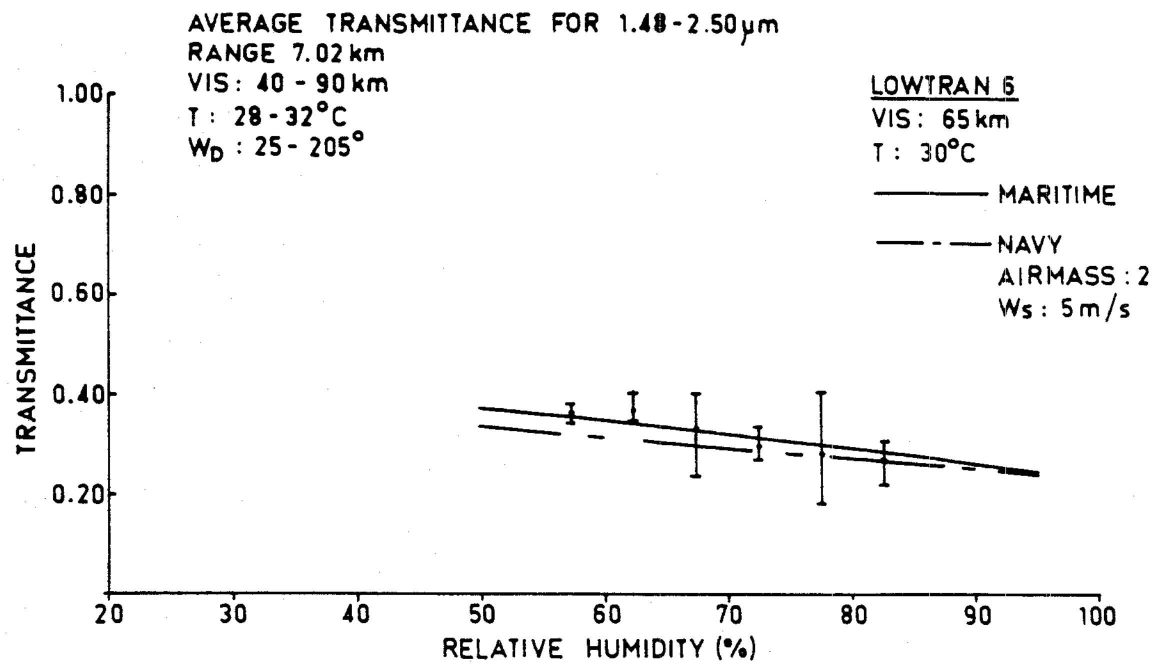


(a)



(b)

Figure 14. Variation of effective transmittance with relative humidity in the 1.48 to 2.50 μm region for maritime conditions within the temperature range 22 to 28°C



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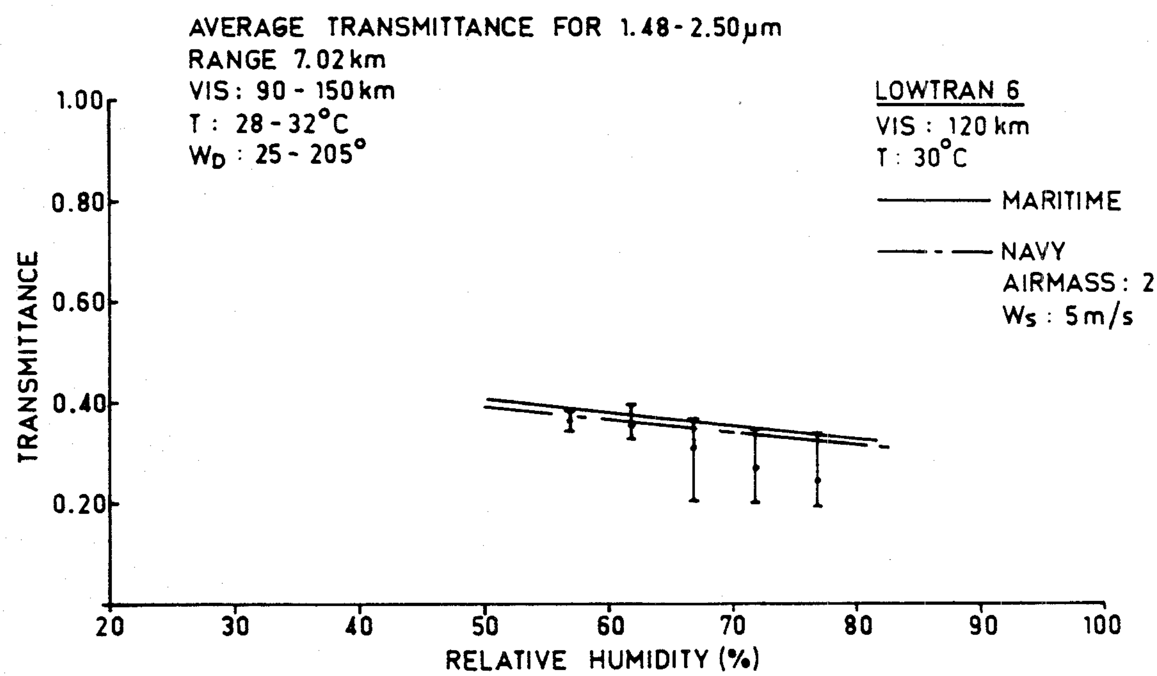
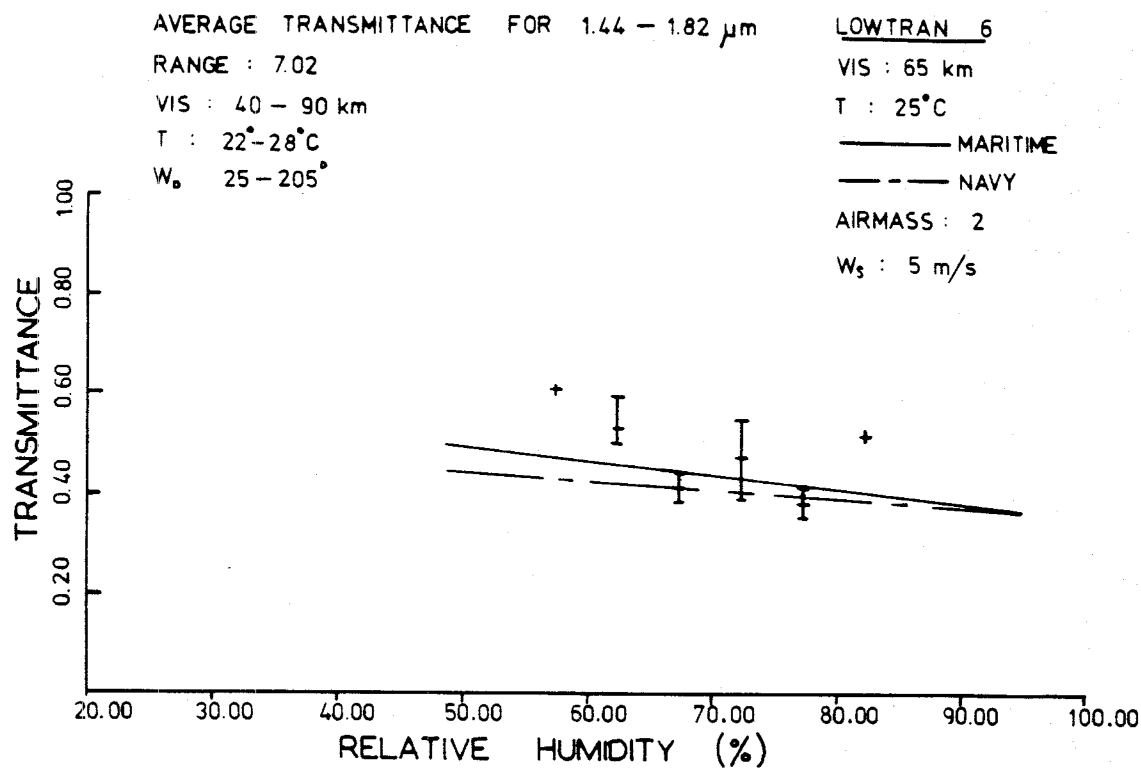
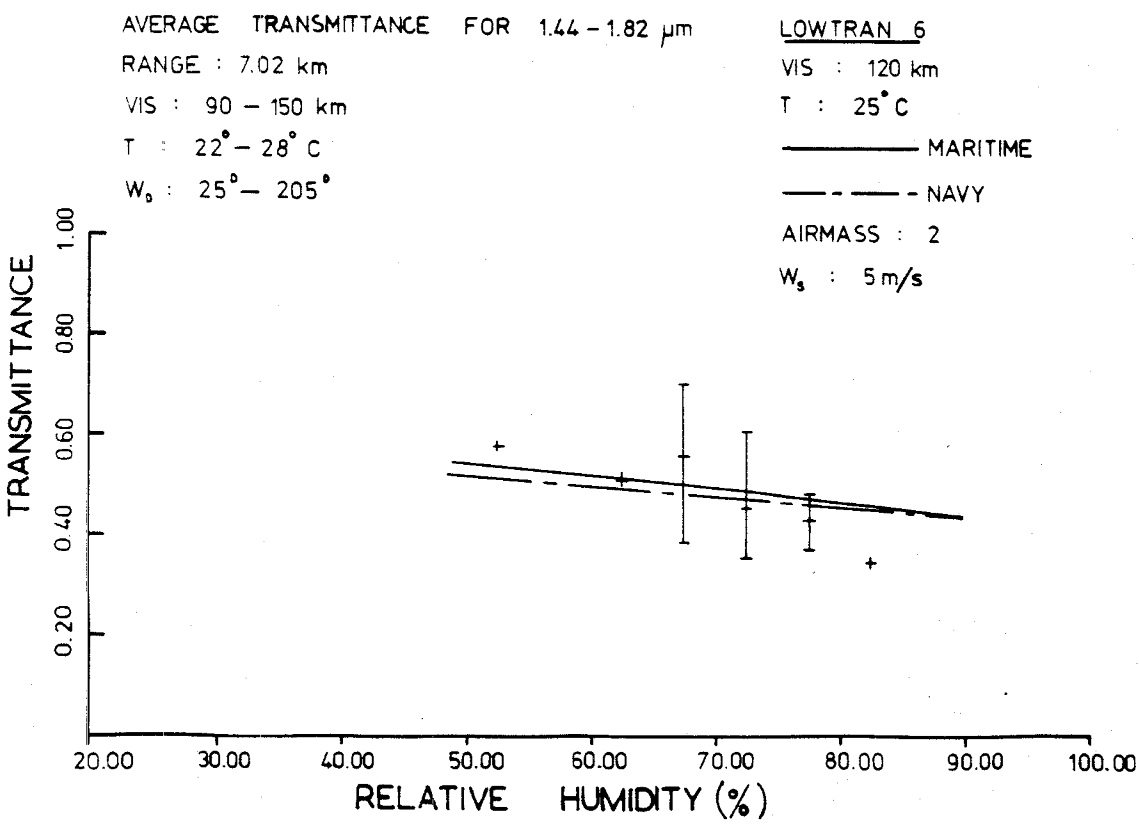


(b)

Figure 15. Variation of effective transmittance with relative humidity in the 1.48 to 2.50 µm region for maritime conditions within the temperature range 28 to 32°C

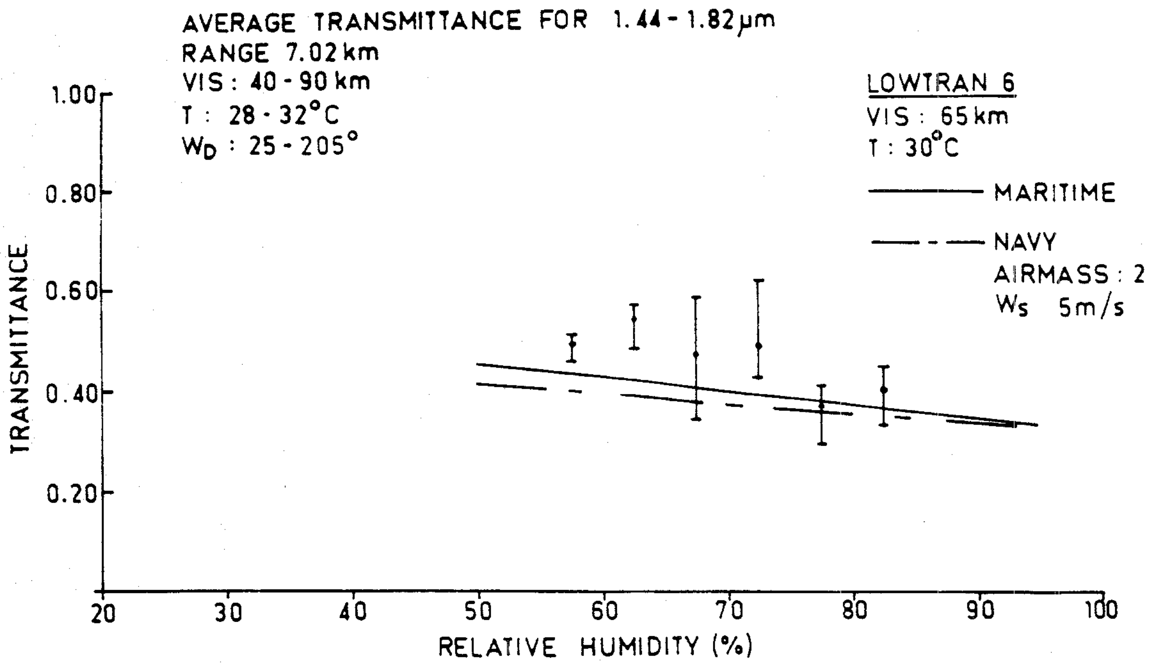


(a)

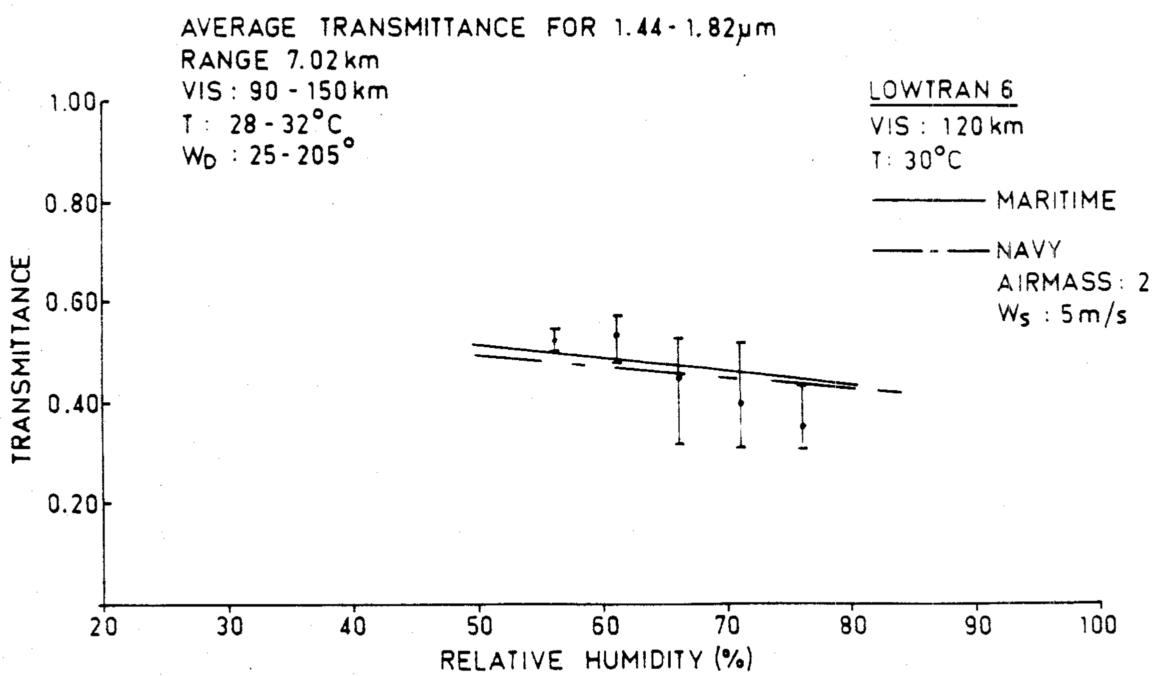


(b)

Figure 16. Variation of effective transmittance with relative humidity in the 1.44 to 1.82 μm region for maritime conditions within the temperature range 22 to 28°C



(a)



(b)

Figure 17. Variation of effective trnsmittance with relative humidity in the 1.44 to 1.82 µm region for maritime conditions within the temperature range 28 to 32°C

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16 SUMMARY OR ABSTRACT:
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Broadband IR transmission data measured at a coastal, tropical maritime site have been compared with LOWTRAN 6 model predictions.

Transmittance data for a 7 km path plotted as a function of absolute humidity have been examined in six spectral regions from 1.5 to 12 μm. A significant discrepancy, which increases with water vapour content, has been found between the measured and predicted data for the 8 to 12 μm region. This discrepancy is believed to be due to errors in the laboratory-determined self-broadening coefficients of water continuum absorption.

Reasonable agreement has been obtained in the 4.4 to 5.4 μm and the 3.5 to 4.0 μm regions, particularly for the former region when water continuum absorption is included in the LOWTRAN model.

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